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EFFECT OF RUN TIMING ON THE EXPLOITATION BY ANGLERS OF ATLANTIC SALMON IN THE MIRAMICHI RIVER

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with an addendum on **'Precision of the Petersen-Lincoln estimator after adjustment for error associated with estimating the tag reporting rate and the size of the recapture sample'**

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ABSTRACT

Randall, R.G., J.A. Wright, and P.R. Pickard. 1991. Effect of run timing on the exploitation by anglers of Atlantic salmon in the Miramichi River. Can. Tech. Rep. Fish . Aquat. Sci. No. 1790: viii + 46.

Exploitation rate of Atlantic salmon by anglers was estimated from mark-recapture data in the Miramichi River from 1966 to 1975 and from 1985 to 1987. During this period, over 12,000 salmon were tagged with Carlin tags at an esturial trap located at Millbank, and over 2000 tags were recovered from angling fishery in various tributaries. Adult salmon enter the Miramichi River in two distinct runs, one early in the season (June- July) and another late in the season (September-October). Recapture data from research traps indicated salmon moved slowly through tidal waters, particularly early-run fish: residence time varied from 4 to 36 days for early-run salmon and from 2 to 11 days for late run salmon. After moving out of tidal waters, salmon became available to anglers throughout all major tributaries of the Miramichi River. Angling seasons, which varied among years and among tributaries within years, generally favoured the exploitation of early-run salmon. Exploitation rate for early-run 1SW salmon averaged 0.34 (annual range 0.18 to 0.54) and for MSW salmon averaged 0.29 (0.10 to 0.49). Exploitation rates of late-run fish were less, averaging 0.10 and 0.12 for 1SW and MSW salmon, respectively. Total exploitation rate varied from one year to the next, depending on the duration of the angling season, and the proportion of the stock that entered the river early in the season. Preliminary analysis of mark- recapture data from the angling fishery indicated that spawning escapement throughout the large Miramichi River may be estimated using mark-recapture techniques. However, several assumptions inherent in the mark-recapture method, particularly tag reporting rates and random distribution of tagged fish, need to be tested annually before reliable results can be obtained.

Keywords: Atlantic salmon, Miramichi River, run timing, angling exploitation, spawning escapement, Petersen-Lincoln estimator, mark-recapture, Carlin tags.

RÉSUMÉ

Randall, R.G., J.A. Wright, and P.R. Pickard. 1991. Effect of run timing on the exploitation by anglers of Atlantic salmon in the Miramichi River. Can. Tech. Rep. Fish . Aquat. Sci. No. 1790: viii + 46.

Le taux d'exploitation du saumon de l'Atlantique par les pêcheurs à la ligne a été évalué d'après les données des reprises de poissons étiquetés dans la rivière Miramichi de 1966 à 1975 et de 1985 à 1987. Pendant cette période, plus de 12 000 saumons ont été marqués avec des étiquettes Carlin à une trappe située dans l'estuaire de Millbank. Plus de 2 000 étiquettes ont été récupérées à partir de la pêche à la ligne dans divers tributaires. Le saumon adulte pénètre dans la rivière Miramichi dans deux montaisons distinctes, dont l'une se produit au début de la saison (juin-juillet) et l'autre, tard dans la saison (septembre-octobre). Les données sur les reprises dans les trappes de recherche indiquent que le saumon se déplace lentement dans les eaux à marée, en particulier le saumon de montaison hâtive. Le temps de séjour varie en effet de 4 à 36 jours pour le saumon de montaison hâtive, tandis que le saumon de montaison tardive y passe de 2 à 11 jours. Après avoir quitté les eaux de marée, le saumon est à la merci des pêcheurs à la ligne dans tous les principaux tributaires de la rivière Miramichi. Les saisons de pêche à la ligne qui varient avec les années et d'un tributaire à l'autre favorisent en général l'exploitation du saumon de montaison hâtive. Le taux d'exploitation du saumon unibermarin (UBM) de montaison hâtive se chiffre en moyenne à 0,34 (écart annuel de 0,18 à 0.54) et celui du saumon pluribermarin (PBM) se chiffre en moyenne à 0.29 (0,10 à 0,49). Les taux d'exploitation du saumon de montaison tardive sont inférieurs, se chiffrant en moyenne à 0,10 et 0,12 pour le saumon UBM et le saumon PBM respectivement. Le taux d'exploitation global varie d'une année à l'autre, en fonction de la durée de la saison de pêche à la ligne et de la proportion du stock qui a pénétré dans la rivière au début de la saison. Les analyses préliminaires des données sur les reprises de poissons étiquetés indiquent qu'il pourrait être possible d'évaluer le taux d'échappée dans l'ensemble de la rivière Miramichi grâce aux techniques de reprise des poissons étiquetés. Il faut toutefois vérifier chaque année plusieurs hypothèses inhérentes à la méthode de reprise des poissons étiquetés, en particulier les taux de récupération des étiquettes et la distribution au hasard du poisson étiqueté, et ce, avant de pouvoir obtenir des résultats fiables.

Mots clés: Saumon de l'Atlantique, rivière Miramichi, moment de la montaison, exploitation par la pêche à la ligne, échappée, estimateur Petersen-Lincoln, reprise des poissons étiquetés, étiquettes Carlin.

INTRODUCTION

Prior to spawning in late autumn, adult Atlantic salmon enter the Miramichi River every month from May to November. During this period, there are generally two distinct peaks in abundance, the first occuring between mid-June and mid-July and the second between mid-September and mid-October (Ruggles and Turner 1973; Randall and Schofield 1988). The relative abundance of early and late-running salmon varies from one year to the next, and it has also changed over the long term. Whereas historically late-running salmon were more abundant than early-running salmon in the Miramichi (Ruggles and Turner 1973), the opposite has been true in more recent years (since the late 1960's), possibly as a result of distant and homewater commercial fisheries which exploit late-running salmon moreso than early-running salmon (Elson 1973).

During their upstream migration, salmon are exploited by anglers in all major tributaries of the Miramichi River above the head of tide. Angling seasons in the Miramichi generally close in early autumn and thus, in contrast to the commercial fisheries, anglers exploit early-run salmon moreso than late-run salmon. Because of annual fluctuations in the relative abundance of early and late-running salmon, exploitation rate on the total spawning run will also fluctuate, being highest in years when returns of late-running salmon are relatively low.

The objectives of this report were threefold: first, to estimate the exploitation rate of salmon by anglers in the Miramichi River, and in particular to compare the exploitation rates of early and late-running salmon. Exploitation rates are estimated from tagging data. The second objective was to examine the feasibility of estimating spawning escapement from angling catch data. The final objective was to identify the tagging and research requirements if mark-recapture data from anglers are going to be used to estimate spawning escapement in the Miramichi River in future.

METHODS

1. TAGGING PROCEDURES

Adult salmon were tagged during their upstream migration at Millbank (Fig. 1) during two periods: annually from 1966 to 1975, and from 1985 to 1987. For the earlier study, salmon were captured and anesthesized using tertiary-amyl-alcohol, retained in a holding box containing water, measured (fork length, mm), weighed (0.1 kg), scale sampled and tagged with Carlin tags tied with fine stainless steel wire. Results of the earlier tagging study have been documented by Turner (1973; 1975; 1976; and 1983). For the latter study, similar tags were used, but the fish were not anesthesized, and only one fish in five was measured and scale sampled. Salmon that were not scale sampled were identified as being either one-sea-winter salmon (1SW, fish < 63 cm) or multi-sea-winter salmon (MSW) on the basis of fork length.

The Millbank trap has been operated in the estuary of the Miramichi River since 1954 (Ruggles and Turner 1973). The trap has the following dimensions and mesh size: the leader is about 92 m in length and has a mesh of 15.2 cm; the trap is about 33.6 m long, 3.7 m wide, and has two trap ends (one upstream and one downstream) connected by a bay portion. Prior to 1977, the trap ends were fished with 8.89 cm mesh; this was reduced to a 5.08 cm mesh in 1977 in order to count gaspereau as well as salmon (E. Schofield, personal communication). The trap was operated from May (after ice-out) to late October or early November each year, and was fished at least once and sometimes twice daily, depending on tides and weather.

During the early tagging period, only a proportion of the salmon trapped at Millbank were tagged each year (usually < 50%). The numbers tagged depended on the total daily catch, weather conditions and the manpower available. For the later tagging period, most fish were tagged (usually > 70%). When daily catches were high and all fish could not be tagged, an attempt was made to tag fish in proportion to their abundance.

2. RECAPTURE DATA

An angling fishery for Atlantic salmon occurs on all major tributaries of the Miramichi River above the head of tide. There are two main branches, the Northwest Miramichi which includes the Little Southwest and Sevogle tributaries, and the Southwest Miramichi which includes the Cains, Renous, Dungarvon, Rocky Brook, and Clearwater tributaries (Fig. 1).

Tags returned by anglers throughout the Miramichi system were carefully documented as to capture date, location, and tag number. Angling catch data were estimated by the New Brunswick Department of Natural Resources and Energy (DNRE). A subsample of anglers were asked to report their catch by major tributary and total catches were then estimated from the subsamples (Hooper 1974). These angling data were available since 1969; angling catches for the period 1966 to 1968 were estimated by Department of Fisheries and Oceans fishery officers (Swetnam and O'Neil 1985).

Salmon were not available to the anglers until they passed through tidal waters in the lower Northwest and Southwest Miramichi tributaries (Fig. 1). Tag recaptures were available from several fisheries in these tidal areas, including commercial trap nets (1966 to 1971), Native fisheries at Eel Ground and Red Bank (mainly after 1971), broodstock removals (mainly in 1966 and 1967), and occasionally from drift nets in Miramichi Bay (1966 to 1971). All tags returned from locations below angling waters were subtracted from the tagged sample (t) before angling exploitation rates and spawning escapements were calculated.

Recapture data were also available from several research counting facilities. These included: 1. Curventon counting fence, located on the lower Northwest Miramichi River, 1966 to 1973; 2. recapture traps, two each located in the Southwest and Northwest tributaries in 1973 (Turner 1983); 3. recapture traps located at the confluence of the Southwest and Northwest tributaries, 1985 to 1987; 4. Bartholomew River counting fence, 1985 to 1987; 5. Dungarvon

barrier, 1985 to 1987; and finally 6. Southwest barrier, located in the headwaters of the south branch of the Southwest Miramichi (1985-1987). With the exception of the recapture traps located in the lower Southwest and Northwest tributaries (numbers 2. and 3. above), objectives for operating these various counting facilities were unrelated to the salmon tagging operation at Millbank. However, recapture data from all counting fences were used to estimate salmon run timing to various locations within the watershed, and to estimate the tag reporting rate by anglers (see below).

3. ESTIMATES OF ANGLING EXPLOITATION RATE AND SPAWNING ESCAPEMENT

Exploitation rate (U) by anglers was calculated as:

$$(1) \quad U = s/t$$

where U was the exploitation rate, s was the number of tags recaptured, and t was the number of salmon tagged.

Exploitation rate was estimated for early-run salmon (U_e) and late-run salmon (U_l) seperately. Confidence limits for U were estimated assuming that s followed a Poisson frequency distribution (Ricker 1975; Seber 1982); therefore 95% confidence limits were calculated from:

$$(2) \quad s+1.92 \pm 1.96\sqrt{s+1} \quad \text{(Ricker 1975; Appendix II)}$$

Exploitation rate for the total season (U) was estimated as:

$$(3) \quad U = (s_e + s_l)/(t_e + t_l)$$

where s_e and s_l was the number of early and late tagged fish recaptured, respectively and t_e and t_l was the number of fish tagged early and late, respectively.

Spawning escapement (M) was estimated as:

$$(4) \quad \hat{M} = (n/U) - n$$

where U was the exploitation rate (equation 3) and n was the angling catch (numbers).

Confidence limits (95%) for M were approximated by substituting the confidence limits for U in equation (4).

The above estimates of angling exploitation rate and population size are based on the Petersen method (Ricker 1975; Seber 1982), which is appropriate if the following conditions were met:

1. Tagged fish had the same natural mortality as untagged fish.

2. All fish had the same probability of being captured by anglers, whether tagged or untagged.

3. Tags were not lost.

4. Tagged fish became randomly mixed with untagged fish, or the distribution of fishing effort was proportional to the number of fish present in different tributaries.

5. All tags were detected and reported on recovery by anglers.

6. Recruitment during the tag-recapture period was negligible.

For this study, conditions 1., 2., and 6. were assumed to be met but were not tested. Assumption 4. was tested by comparing s/n ratios (that is, the ratio of tagged to untagged fish in the angling catch) in different tributaries, and assumptions 3. and 5. were tested by comparing s/n ratios at recapture traps to s/n ratios as reported by anglers.

RESULTS

1. RUN-TIMING

For the period 1966 to 1987, annual counts of salmon at Millbank trap ranged between 810 and 9989 1SW salmon and between 199 and 1934 MSW salmon (Table 1). For 1SW salmon, the proportion of early-run fish (May to August) varied substantially, from 0.20 (1967) to 0.99 (1985) of the total run. Similar fluctuations in run-timing were observed for MSW salmon: proportion early-run fish varied from 0.07 (1967) to 0.96 (1982). Generally, for both 1SW and MSW salmon, early-run fish have been predominant (> 50% of the run) in most years since 1969 (Fig. 2). Among the different years, the proportion of 1SW salmon that entered the river early was correlated with the proportion of MSW salmon that entered the river early in the same year (Fig. 3).

Run-timing within specific sections of the Miramichi River was calculated by comparing tagging dates with recapture dates at the six research counting facilities (Table 2). Average residence time in tidal areas was estimated by

comparing tagging dates at Millbank to recapture dates in Millerton-Bryenton and the Enclosure park (south side) in the Southwest and Stathadam and the Enclosure (north side) in the Northwest; these sites are located below the head of tide where fish first become available to anglers. For early-run fish, residence times varied from 4 to 11 days for 1SW salmon, and from 12 to 36 days for MSW salmon. Late-run fish migrated through tidal areas more quickly: average residence times were 2 to 6 days for 1SW fish, and from 3 to 11 days for MSW salmon. Average duration from tagging to recapture date at more upstream counting facilities (Bartholomew, Dungarvon, and Curventon) was variable, ranging from 17 (1SW salmon at Bartholomew) to 74 days (MSW salmon at Curventon). Generally, 1SW salmon migrated more quickly upstream than MSW salmon, and late-run fish migrated more quickly than early-run fish.

2. ANGLING SEASONS

In the main Southwest Miramichi, which produces the largest angling catch of any tributary, the angling season varied from year to year during the period of tagging. From 1966 to 1970, the annual duration of the angling season was 139 days; the season began on May 15, and continued until September 30 (Table 3). From 1971 to 1975, the season was reduced to 124 days by invoking an earlier closing date (September 15). In more recent years (1985 to 1987), the duration of the angling fishery was further reduced to 114 days by delaying the opening date to 8 June (Table 3). In all years, early-run fish were accessible to anglers, but the proportion of the late-run available varied and depended on the closing date of the fisheries. Elsewhere in the Miramichi watershed, angling seasons were specific to each tributary, but trends in opening and closing dates were similar to the Southwest Miramichi.

3. NUMBERS OF SALMON TAGGED AND NUMBERS RECAPTURED

During the 13 years of tagging, 4306 MSW salmon and 8451 1SW salmon were tagged and released. About 56% of MSW salmon and 68% of 1SW salmon tagged were early-run fish. Proportions of the early-run MSW salmon tagged at Millbank ranged from 0.12 to 0.89, and for the late-run 0.12 to 1.00 (Table 4). For 1SW salmon, proportions ranged from 0.05 to 0.80 for early-run and from 0.06 to 1.00 for late-run fish.

A total of 1382 tags from 1SW salmon and 716 tags from MSW salmon were recovered from various fisheries in the year of tagging (Table 5). Proportions recaptured ranged between 0.10 and 0.40 for 1SW salmon, and between 0.02 and 0.49 for MSW salmon. Most recaptures came from the angling fisheries: for all years combined, 71% of 1SW recaptures and 52% of MSW recaptures were from anglers.

Recaptures of tagged salmon from research counting facilities were summarized by year of capture in Table 6. For all years, a total of 239 1SW salmon and 102 MSW salmon were recaptured at these various facilities.

4. ASSUMPTIONS FOR ESTIMATING EXPLOITATION RATES

4.1 RANDOM MIXING OF TAGGED SALMON ABOVE MILLBANK

Ratios of marked to unmarked fish (*s/n*) were compared in the two major branches of the Miramichi, the Northwest and Southwest tributaries, to test whether or not tagged fish became randomly distributed in the population after tagging. Recapture data from the upstream research traps and from anglers were used. Recapture samples from the tidal traps located about 12 km above Millbank indicated random mixing of tagged fish with untagged fish in all years (Table 7). Similar *s/n* ratios were observed in most years from the angling samples from the Northwest and Southwest branches (Table 8). However, a significant difference in the tagged to untagged ratio between tributaries was observed in 1985. As noted earlier (condition 4.), random mixing of marked fish is not necessary if angling effort was proportional to the abundance of salmon in the two tributaries. In the absence of information to test whether or not this was the case, inferences from tagging data in 1985 should be made with caution.

4.2 TEMPORAL VARIATION IN TAGGED TO UNTAGGED RATIOS

Numbers of salmon tagged at Millbank were not always proportional to the trap catch. In some years a higher proportion of early fish were tagged than late fish (eg. 1968 for MSW salmon), while in other years the opposite was true (1973 for 1SW salmon) (Table 4). Because the angling season favours the exploitation of early-run salmon, estimates of total season exploitation rate would be biased if the number of fish tagged was not proportional to the run size. Exploitation rate would be underestimated if the proportion of late fish tagged was greater than the proportion of early fish tagged (Appendix I).

To adjust for this potential bias, marked samples were corrected so that equal weight was given to early and late marked (*t*) and recapture samples (*s*):

$$(5) \quad Cor = a1/a2$$

where a1 was the proportion of early fish tagged and a2 was the proportion of late fish tagged. Actual numbers of fish tagged (t_l) and recaptured (s_l) during the late period were adjusted by multiplying by the correction factor (*Cor*) before using equation (3). An example of this adjustment is given in Appendix I. Correction factors for each year are given in Table 4.

4.3 MORTALITY OF TAGGED FISH, TAG LOSS, NON-REPORTING AND NON-DETECTION OF TAGS BY ANGLERS

Numbers of tags returned by anglers would only be a fraction of the total potential tags available to them in a perfect tag-recapture experiment.

Non-reporting of tags, tag loss, and non-detection of tags are all factors that would decrease the recapture sample (s) and lead to an underestimate of exploitation rate (U). The magnitude of this potential bias was estimated by comparing the tagged to untagged ratio at the recapture traps to the ratio from the angling sample. (Note that this comparison assumes that the angling catches were estimated without bias. See Addendum). In all years, the s/n ratio from trap data was significantly higher than from the angling data, indicating a reporting rate that ranged from 0.38 to 0.55 (Table 9).

Because of the time interval between tagging and recaptures at the upstream traps (Table 2), some tag loss/tag mortality may also have occurred during this period. Estimates of exploitation rate were also made assuming the tag loss/tag mortality rate in tidal waters was 0.2.

As a result of the above observations, exploitation rate was estimated using four different assumptions:

(1) no tag loss or mortality and a tag reporting and detection rate of 100%; this would be a minimum estimate of exploitation rate.

(2) a tag loss and tag mortality rate of 0.2.

(3) a tag loss, mortality rate and reporting rate of 0.55 (1966 to 1975), 0.38 (1985), 0.54 (1986) and 0.52 (1987) (Table 9).

(4) a tag loss, mortality rate of 0.2 in tidal waters, and an additional rate as indicated in 3.; this would represent a maximum estimate of exploitation rate.

Assumption 3 was judged to be the most reasonable for estimating exploitation rates.

5. ANGLING EXPLOITATION RATE

Data used to calculate exploitation rates by anglers on early and late running salmon in the Miramichi River are summarized in Table 10. Exploitation rate (as estimated using assumption (3) above) was significantly greater for salmon that entered the Miramichi River early than late. For 1SW salmon, the average exploitation rate for early fish was 3.4 times greater than for late fish, and for MSW salmon, the rate was 2.4 times greater for early fish (Table 11). Total exploitation rate for 1SW salmon was estimated to average 0.28 (range 0.17 to 0.46). Exploitation rate for MSW salmon was lower, averaging 0.20 (0.08 to 0.29). There was a significant correlation among years between exploitation rate of 1SW salmon and MSW salmon (Fig. 4).

Duration of the angling season had a significant effect on exploitation rate. When the season was reduced by 2 weeks from September 30 (1966 to 1970) to September 15 (1971 to 1975), exploitation rates decreased by an average of 0.05 for 1SW salmon and by 0.04 for MSW salmon (Table 12). As expected, exploitation of late-run salmon was reduced proportionally more than early-run

salmon.

Annual exploitation rate also depended on run-timing. For years when the angling season was constant (1971 to 1975), exploitation rate was directly correlated to the proportion of fish that entered the river early (Fig. 5).

Exploitation rates of salmon by anglers as calculated using the four different assumptions for reporting, tag loss, mortality and detection rates (text page 7) are compared in Appendix II.

6. ESTIMATED SPAWNING ESCAPEMENT AND TOTAL RETURNS TO THE RIVER

Estimates of spawning escapement and total river returns as estimated using equation (4) and assumption 3 (page 7) are provided in Table 13. Confidence intervals were usually within 25% of the estimates, indicating reasonable precision (but see Addendum). Spawning escapements as estimated from angling data were usually greater than estimates from Millbank trap data (Randall and Schofield 1988), but general trends were similar for both sets of data (Fig. 6).

DISCUSSION

Exploitation rate by anglers on Atlantic salmon in the Miramichi River was 2 to 3 times greater for fish that migrate upstream early (May to August) than for fish that enter the river later (September to November). Angling seasons favoured the exploitation of early-run salmon. Total exploitation varied significantly from one year to the next, depending on the duration of the angling season, and on the proportion of the stock that returned to the river early. If most fish enter the river early, the potential for high exploitation rates is greater than if a significant portion of the stock enter the river in late season. The effect of run-timing on potential exploitation has important implications for estimating spawning escapement: the use of a constant exploitation rate may be misleading in the Miramichi River where the proportion of early versus late-running salmon varies from one year to the next.

Exploitation rate by anglers was about 1.4 times greater for 1SW salmon than for MSW salmon (Table 11 and 12). A similar difference was observed in the Restigouche River, where visual counts of spawners and angling catches indicated a higher exploitation of small than large salmon (Randall et al. 1988). These observations were in contrast to an earlier study on the Miramichi however. Elson (1974), using counting fence and creel census data for early-run salmon in the Northwest Miramichi, estimated an exploitation rate of 0.39 for 1SW salmon, but a higher rate of 0.52 for MSW salmon (Table 14). Relative exploitation rates of small versus large salmon in the Miramichi River requires further investigation.

For rivers like the Miramichi which have a high proportion of 1SW salmon, it is easier to obtain suitable numbers of recaptures of 1SW fish for

mark-recapture studies than MSW salmon, and therefore more reasonable estimates of exploitation rates can be obtained. The correlation between exploitation rates of 1SW and MSW salmon (Fig. 4) however, suggest that it is possible to estimate the MSW exploitation rate from 1SW data. The vulnerability of both age groups to anglers seem to be affected by similar factors from one year to the next.

Exploitation rates for the total salmon stock in the Miramichi River ranged between 0.10 and 0.46, depending on the year, run-timing (Table 11), and duration of the angling season (Table 12). Similar but somewhat higher rates were reported by Elson (1974): annual rates ranged from about 0.14 and 0.76, with an average of 0.31. In the Gaspé region of Québec, where salmon runs are predominantly early-run, exploitation rates typically average 0.2 to 0.4, but they can be as high as 0.6 in small rivers (G. Landry, pers. comm.). Exploitation rates from several salmon rivers in Eastern North America are compared in Table 14. It is apparent that angling exploitation can have a significant impact on freshwater populations of adult salmon. However, total exploitation rate can be effectively controlled by season limits (Table 12).

During his study of angling exploitation rates in the Northwest Miramichi River, Elson (1974) found that tagging data significantly underestimated exploitation rates compared to counting fence and creel census data. A correction factor of 71% had to be applied to tag recapture data to achieve a comparable exploitation rate to the counting fence estimate. Elson attributed this discrepancy to the non-random distribution of tagged fish in the upriver population, and to low tagged to untagged fish ratios (i.e., a dilution factor). For this study, tagging at Millbank resulted in a very low tagging ratio (about 1%; Table 9), but tagged fish seemed to be randomly distributed throughout the two major tributaries. However, significantly lower tagged/untagged ratios in the angling fishery compared to research traps indicates that a combination of non-reporting of tags, tag mortality, and non-detection of tags was a major factor in the Miramichi system. These factors may have affected Elson's study as well. Estimates of exploitation and spawning escapement are sensitive to the tag reporting and tag mortality rates, and this was the most significant weakness in these mark-recapture estimates. Research is required to confirm the tentative reporting rates observed in this study.

After corrections were made for the above non-reporting/tag mortality factor, estimates of spawning escapement from the tag-recapture data were correlated with estimates of spawning escapement which were obtained independently from Millbank trap data (Randall and Schofield 1988). Thus it is possible to use angling mark-recapture data to estimate spawning escapement in the Miramichi River. However, further work is required to investigate the assumptions and conditions that must be met for Peterson estimates to be reliable.

FUTURE RESEARCH

Preliminary data from the Miramichi River suggest the following information should be considered before future mark-recapture estimates of

exploitation rates and spawning escapements are initiated:

1. Total population size (N) of Atlantic salmon in the Miramichi river has been estimated to vary between roughly 50,000 and 200,000 fish among years (Table 13). With angling exploitation rates which averaged between 0.20 to 0.30 (Table 12), angling catches can provide large sample sizes (n) to examine for tagged fish. With these rough estimates of the potential sizes of N and n, it is possible to identify the numbers of salmon that need to be tagged to estimate spawning escapement within a certain level of precision using mark-recapture data (Robson and Regier 1964).

2. However, angling catches in the Miramichi River are also estimated. Variances associated with the catch data should be reported and incorporated into the overall variance associated with the estimate of spawning escapement (see Addendum).

3. Reporting rate by anglers must also be estimated on an annual basis, by comparing s/n ratios at research facilities to s/n rations in angling data. Field census by research personnel, possibly at index angling camps where data are reliable, would also be useful. Variances associated with estimates of the reporting rate should also be incorporated into the variance associated with the estimate of spawning escapement (see Addendum).

4. Using the total angling catch from the Miramichi River as the recapture sample for estimating population size and spawning escapement is initially appealing because it provides a large sample size. However, the level of precision may be undesirably low if the standard error associated with the estimate of angling catch is high, and if the measurement error of estimating tag returns is also high (Addendum). The magnitude of both these potential sources of error is presently unknown. Whether or not estimates of total angling catch will be used in future to estimate numbers of spawners of Atlantic salmon in the Miramichi River will depend on the magnitude of these sources of error.

5. Another possibility would be to use subsamples of angling catch to estimate population numbers, rather than total catch. Angling catches at many of the angling lodges located throughout the Miramichi watershed are routinely recorded accurately in a daily log by lodge managers and angling guides. Information on tag recaptures could also be provided. Under these circumstances, and possibly with the use of trained observers, information on angling catch and tag recaptures may be obtained without sampling or measurement error. The sample size required (number of camps, total angling catch, and numbers of recaptures) to achieve a desired level of precision could be determined from standard mark-recapture theory (Robson and Regier 1964).

6. If Millbank trap is used as the only tagging site, the potential tagged/untagged ratio will remain low, probably close to 1%. Assumptions inherent in mark-recapture procedures need to be tested more thouroughly,

preferably with higher *s/n* ratios than was the case in this study. One option would be to carry out a detailed mark-recapture experiment in a smaller tributary, preferably where the population size is known (eg. via a counting fence) . Assumptions of the mark-recapture technique (random mixing of tagged fish, tag retention, reporting rate by anglers etc.) could then be thoroughly tested.

7. Mortality rate of tagged fish, both in the short and long term needs to be estimated. Retention of tagged fish in observable enclosures would be useful for this purpose.

8. Detection rate of tagged fish by anglers needs to be investigated; field observations as in 3. may be feasible.

9. Random tagging is essential. Both early-run and late-run fish should be tagged in direct proportion to their abundance. Completely randomized tagging would eliminate the need to correct for early versus late biases as was done in this study (equation 5).

10. Tagging should preferably be done above tidal waters to avoid the problem of interception of tags before they become available to anglers.

ADDENDUM

Precision of the Petersen-Lincoln estimator after adjustment for error associated with estimating the tag reporting rate and the size of the recapture sample.

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Background

Conventionally, in the Petersen-Lincoln estimator of population size, the recapture sample (n) is assumed to be free of sampling error and the number of recaptured tags (s) is assumed to be free of measurement error. Neither of these assumptions holds for the tag-recapture data available from the Miramichi River. Angling catch for the total river is estimated from records submitted by a subsample of anglers (Hooper 1974); at present, the variance of these annual estimates of catch is not known. Reporting rate of tag recaptures by anglers is also estimated (see text above) but with unknown variance. Because these two sources of error are not taken into account, confidence intervals associated with the estimates of spawning escapement and population size in the previous section (Table 13) are too optimistic. In this addendum, a variance formula for estimating spawning escapement is developed which takes into account these additional sources of error. Bowen and Sergeant (1983), in a mark-recapture study of harp seals, addressed the problem of estimation of second sample size and non-reporting of tags in a similar but somewhat different manner.

Theoretical Notes

Let N denote the population size, t the number of individuals tagged and released at time 1, n the number captured at time 2, and s the number captured at time 2 that have tags. Then the Petersen-Lincoln estimate of the population size is

$$\hat{N}=nt/s$$

with its variance estimated as

$$Var(\hat{N}) = nt^2(n-s)/s^3$$

The latter can be derived as follows. Both n and t are regarded as known and fixed; thus s is the only random variable. Then

$$Var(\hat{N}) = (nt)^2 Var(1/s)$$

Now, in general,

$$Var(f(s)) = \left[\frac{\partial f(s)}{\partial_s}\right]^2 \sigma_s^2$$

and with $f(s) = 1/s$, $\partial f(s)/\partial s = -1/s^2$ while σ_s^2 can be estimated as $n(s/n)(1-s/n) = s(n-s)/n$. Bringing together the above parts yields the given standard formula (Ricker 1975; Seber 1982).

Note that the Petersen estimator is biased. The bias is approximately $N(N-t)/nt$. If $t = 0.01N$ (i.e., 1% of the population tagged) and $n = cN = 0.2N$ for a catch rate of $c = 20\%$, the bias is of the order of 495 and thus would appear to be negligible for the population sizes under consideration.

For management purposes, a primary interest is to estimate not only population size (N), but also the size of the spawning escapement, $N - n$, estimated as $\hat{N} - n$. One problem is that n is not known but estimated from a subsample of anglers. That is, n should also be treated as a random variable. As noted above, the precision of n is not known at this time. Assume that the standard error of n is kn, or $Var(n) = k^2n^2$ and consider the effect of different values of k, namely 0.01, 0.05, 0.1 and 0.2. Then

$$Var(\hat{N}) = t^2 \frac{E^2(n)}{E^2(s)}\left[\frac{Var(n)}{E^2(n)} + \frac{Var(s)}{E^2(s)} - 2\frac{Cov(n,s)}{E(n)E(s)}\right].$$

Assume that n and s are independent; thus $Cov(n,s) = 0$. In the normal course of events this would certainly not be the case; in the present situation, however, it may not be a too unreasonable assumption. As noted above, n is not known but is estimated from a subsample of anglers. Further, s is not obtained by direct count, since not all tags are returned by anglers. Indeed the comparison with research counting facilities suggests that only something of the order of 50% of the tags are returned by anglers. Some allowance also should be made for mortality and tag loss from other causes. These features would tend to weaken any association between n and s. Nevertheless, what association there is can be expected to be positive so that the omission of the covariance term in the expression for $Var(\hat{N})$ should result in an overestimate of the variance, i.e., a conservative estimate of precision.

In light of the above, in determining $Var(s)$, we must also take into account the fact that s is estimated rather than measured. Let $s_r = ps$, i.e. p is the proportion of tags returned by anglers. (It may be supposed that p also makes allowance for mortality and other tag loss). Recapture is made at the reseach facilities as well as by anglers. Tag return is, of course, no problem with the former. However, since in recent years (Table 9) recaptures at research facilities number approximately 1/12 of those made by anglers, for present purposes, this complication may be ignored.

Thus, under the seemingly reasonable assumption that s_r and p are independent,

$$Var(s) = Var(S_r/p) = \frac{E^2(s_r)}{E^2(p)}\left[\frac{Var(s_r)}{E^2(s_r)} + \frac{Var(p)}{E^2(p)}\right].$$

Now we may take $E^2(s_r)/E^2(p) = p^2s^2/p^2 = s^2$ and $Var(s_r) = ps(n-ps)/n$. For convenience, let $Var(p) = a^2p^2$ and consider $a = 0.01$, 0.05, 0.10, say. Then

$$Var(s) = s^2[(n-ps)/nps + a^2] = s(n-s)/n + s(1-p)/p + s^2a^2.$$

If all tags were returned, then $p = 1$, $a = 0$ and the above reduces to $s(n - s)/n$. Note that the smaller the value of p, i.e., the smaller the proportion of tags returned, the greater $Var(s)$.

Finally, recall that the estimate of the spawning escapement is $\hat{M} = \hat{N} - n = nt/s - n$. With n fixed, $Var(\hat{M}) = Var(\hat{N})$, but with n random,

$$Var(\hat{M}) = Var(nt/s) + Var(n) - 2Cov(nt/s, n)$$

Now

$$Var(nt/s) = \frac{t^2n^2}{s^2}[k^2 + Var(s)/s^2] .$$
$$= t^2n^2 Var(s)/s^4 + t^2n^2k^2/s^2 .$$
$$Var(n) = k^2n^2$$

and

$$-2Cov(nt/s, n) = -2tVar(n)E(1/s) = -2tk^2n^2E(1/s) .$$

Further

$$E(1/s) = (1/s)[1 + Var(s)/s^2] .$$

whence

$$Var(\hat{M}) = k^2n^2(1 - t/s)^2 + tn^2(t/s - 2k^2)Var(s)/s^3$$
$$= k^2n^2(1 - t/s)^2 + tn^2(t/s - 2k^2)[(n-s)/n + (1-p)/p + sa^2]/s^2$$
$$= n^2[k^2(1 - t/s)^2 + (t/s)(t/s - 2k^2)/s][(n-s)/n + (1-p)/p + sa^2] .$$

Note that when $k = 0$ (n measured wihout error), $p = 1$ and $a = 0$ (all tags returned, etc.) the above reduces to $nt^2(n - s)/s^3$.

Relative standard errors $[(\sqrt{Var(\hat{M})}/M)(100)]$ have been calculated for combinations of the following:

$$N = 50000, 100000, 200000$$
$$n = 0.2N, 0.3N$$
$$(t,s) = (0.01N, 0.01n),\ (0.02N, 0.02n),\ (0.04N, 0.04n)$$
$$p = 1.0,\ 0.5$$
$$a = 0,\ 0.01,\ 0.05,\ 0.10$$
$$k = 0,\ 0.01,\ 0.05,\ 0.10,\ 0.20$$

and the results are presented in Table 15(a-f).

Several points are worth noting from Table 15. First, although the relative precision is somewhat smaller for $p = 1$ than $p = 0.5$ (where p is the tag reporting rate), the difference is not great, suggesting little effect of p. This however would not be the case if p was reduced to something of the order 0.1. Note that the combinations of $p = 1$ and $a > 0$ are somewhat artificial (all

tags returned but with a 'measurement error', an addition to the 'sampling error' in s. Nevertheless these cases serve to provide a limit situation.

The pattern for $k = 0$, $a = 0$ is essentially as would be expected. The relative precision increases with increasing t for fixed N, and with increasing N for fixed t/N. n/N has little effect although the relative precision is slightly better for $n/N = 0.3$. However, exactly the opposite results were obtained for $k = 0.2$, $a = 0.1$, and transitional stages were observed for values of k,a ranging between 0.05 and 0.1. There was a negligible deterioration in precision with $k = 0.01$ and/or $a = 0.01$.

The loss of precision with increasing k, other parameters fixed, was expected and consistent as was the loss of precision with increasing a. What at first seemed paradoxical was the gain in precision with increasing N for fixed t/N and n/N for some combinations of k and a, but a loss of precision for other combinations. Likewise, there was also a gain in precision with increasing t for fixed N and n at some combinations of k and a and a loss at other combinations. The gains occur with the smaller values of k and a, the losses with the larger values, while at intermediate values the trend on N (or t) was not always monotonic (over the range considered). This phenomenon seemed to be more strongly related to a (the uncertainty in p and hence in s) than to k (the uncertainty in n). It might be thougnt that the greater the value of s, the number of recovered tags, the better off one might be; this, however, does not appear to be the case if that number is imprecisely estimated. Observe that the elementary formula for the variance of the Petersen-Lincoln estimate, namely $nt^2(n - s)/s^3$ has a quadratic in n and s in the numerator, but a cubic in s in the denominator. One might then argue that the greater the absolute imprecision in s (and, hence, the greater the value of s for a fixed relative precision - or the greater the relative imprecision for a fixed s, large) the greater the effect on the variance of the estimate.

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REFERENCES

Anon. 1988. Report of the study group on the North American salmon fishery. International Council for the Exploration of the Sea. C.M. 1988/M: 4.

Anon. 1989. Report of the study group on the North American salmon fishery. International Council for the Exploration of the Sea. C.M. 1989/M: 3.

Bowen, W.D. and D.E. Sergeant. 1983. Mark-recapture estimates of harp seal pup (*Phoca groelandica*) production in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 40:728-742.

Chadwick, E.M.P. 1982. Recreational catch as an index of Atlantic salmon spawning escapement. International Council for the Exploration of the Sea. C.M. 1982/M: 43.

Elson, P.F. 1973. Genetic polymorphism in Northwest Miramichi salmon in relation to season of river ascent and age at maturation and its implication for management of the stocks. International Commission for the Northwest Atlantic Fisheries Res. Doc. 73/76: 6 p.

Elson, P.F. 1974. Impact of recent economic growth and industrial development on the ecology of Northwest Miramichi Atlantic salmon (Salmo salar). J. Fish. Res. Board Can. 31:521-544.

Gray, R.W. 1986. Biological characteristics of Atlantic salmon (Salmo salar L.) in the upper LaHave River basin. Can. Tech. Rep. Fish. Aquat. Sci. 1437: 45 p.

Hooper, W.C. 1974. The New Brunswick Atlantic salmon sport fishery, 1969 to 1973. N.B. Dept. Nat. Resources Fish. Manage. Rept. 4:32 p.

Jessop, B.M. 1986. Atlantic salmon (Salmo salar) of the Big Salmon River, New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. No. 1415. xii + 50 p.

Randall, R.G., and E.J. Schofield. 1988. Status of Atlantic salmon in the Miramichi River, 1987. CAFSAC Res. Doc. 88/49, 34 p.

Randall, R.G., G. Landry, A. Madden, and R. Pickard. 1988. Status of Atlantic salmon in the Restigouche River, 1987. CAFSAC Res. Doc. 88/41, 37 p.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191: 382. p.

Robson, D.S. and H.A. Regier. 1964. Sample size in Petersen mark-recapture experiments. Tran. Am. Fish. Soc. 93:215-226.

Ruggles, C.P., and G.E. Turner. 1973. Recent changes in stock composition of

Atlantic salmon (Salmo salar) in the Miramichi River, New Brunswick. J. Fish. Res. Board Can. 30:779-786.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. MacMillan Publishing Co. Inc., New York, 654 p.

Turner, .G.E. 1973. Migration route and timing of Miramichi River salmon (Salmo salar) as indicated from recaptures of tagged smolt and adult salmon. ICES C.M. 1973/M:23, 13 p.

Turner, G.E. 1975. Timing of migration of Atlantic salmon (Salmo salar) within the Miramichi River system, New Brunswick. ICES C.M. 1975/M:24, 4 p.

Turner, G.E. 1976. Exploitation of Atlantic salmon (Salmo salar) in the Miramichi River system, including the bay and estuary, as revealed by wild smolt and adult salmon tagging. ICES C.M. 1976/M:16, 11 p.

Turner, G.E. 1983. An efficiency estimate of the Millbank estuarial sampling trap, Miramichi River, New Brunswick, 1973. CAFSAC Res. Doc. 83/78.

Swetnam, D.A.B., and S.F. O'Neil. 1985. Collation of Atlantic salmon sport catch statistics, Maritime Provinces, 1960-69. Can. Rep. Fish. Aquat. Sci. No. 533. ix + 289 p.

Table 1. Counts of 1SW and MSW salmon at Millbank, 1966 to 1987. Counts are divided into early (May-August) and late periods (September-November).

Year	Early		Late		Total		Proportion early	
	1SW	MSW	1SW	MSW	1SW	MSW	1SW	MSW
1966	4563	309	5426	1323	9989	1632	0.46	0.19
1967	1508	73	6215	924	7723	997	0.20	0.07
1968	2493	292	746	1122	3239	1414	0.77	0.21
1969	3224	339	1126	328	4350	667	0.74	0.51
1970	1826	125	658	120	2484	245	0.74	0.51
1971	1849	375	113	24	1962	399	0.94	0.94
1972	2377	934	166	217	2543	1151	0.93	0.81
1973	1490	478	960	654	2450	1132	0.61	0.42
1974	2948	864	1090	927	4038	1791	0.73	0.48
1975	2954	628	594	580	3548	1208	0.83	0.52
1976	4072	641	867	302	4939	943	0.82	0.68
1977	1249	1189	256	745	1505	1934	0.83	0.61
1978	1150	535	118	158	1268	693	0.91	0.77
1979	2157	257	343	61	2500	318	0.86	0.81
1980	1802	837	337	256	2139	1093	0.84	0.77
1981	2020	173	154	26	2174	199	0.93	0.87
1982	2593	392	72	16	2665	408	0.97	0.96
1983	770	226	40	19	810	245	0.95	0.92
1984	879	257	131	76	1010	333	0.87	0.77
1985	901	287	11	24	912	311	0.99	0.92
1986	1324	345	439	124	1763	469	0.75	0.74
1987	1146	223	126	68	1272	291	0.90	0.77

Table 2. Duration (days) from time of tagging at Millbank to time of recapture at various research counting facilities of Atlantic salmon in the Miramichi River. Locations of counting facilities are shown in Fig. 1. Data for Millerton-Bryenton, Strathadam and Curventon are updated from Turner (1975).

Location	Distance from Millbank (km)	Early-run								Late-run							
		1SW				MSW				1SW				MSW			
		n	mean	SE	range	n	mean	SE	range	n	mean	SE	range	n	mean	SE	range
Millbank	0	42	11.2	2.3	0–63	8	26.6	9.4	6–69	10	2.2	0.7	0–7	0	—	—	—
SW Miramichi																	
1. Enclosure	14.5	18	3.6	0.9	1–15	7	26.3	9.6	2–66	13	1.7	0.2	1–3	4	6.5	3.1	2–15
2. Millerton-Bryenton	25.8	5	11.2	4.8	3–29	14	30.2	4.6	11–71	49	3.4	0.4	1–19	21	4.6	0.9	1–13
3. Bartholomew	57.7	14	16.9	3.8	2–49	1	62.0	—	—	0	—	—	—	1	7.0	—	—
4. Dungarvon		9	26.2	8.1	9–71	—	—	—	—	—	—	—	—	—	—	—	—
NW Miramichi																	
1. Enclosure	14.5	13	5.5	2.3	1–29	4	11.5	6.2	1–25	5	2.8	1.0	1–6	2	2.5	—	1–4
2. Strathadam	20.8	2	7.0	—	6–8	5	36.4	11.6	10–66	22	6.4	1.1	1–18	15	10.7	1.8	1–28
3. Curventon	48.0	28	18.8	3.8	0–75	13	74.4	15.1	11–139	2	40.0	—	33–47	4	34.3	6.2	20–50

Table 3. General angling seasons in the Southwest Miramichi, 1966 to 1975 and 1985 to 1987. Specific sections of the upper Southwest Miramichi were sometimes closed within the dates indicated. Data sources: 1966-1975 (S. O'Neil, pers. comm.) 1985-1987 (Randall and Schofield 1988).

Year	Angling dates		Start date (Julian)	Duration (days)
1966	15 May	30 Sep	135	139
1967	15 May	30 Sep	135	139
1968	15 May	30 Sep	135	139
1969	15 May	30 Sep	135	139
1970	15 May	30 Sep	135	139
1971	15 May	15 Sep	135	124
1972	15 May	15 Sep	135	124
1973	15 May	15 Sep	135	124
1974	15 May	15 Sep	135	124
1975	15 May	15 Sep	135	124
1985	08 Jun	30 Sep	159	114
1986	08 Jun	30 Sep	159	114
1987	08 Jun	30 Sep	159	114

Table 4. Numbers of MSW and 1SW salmon tagged during the early and late runs at Millbank trap. Eligible tags were total numbers tagged minus tag removals in tidal waters prior to the angling fishery. Cor is a correction factor for estimating exploitation rate (see text, equation 5).

Year	Early-run			Late-run			Cor
	Number tagged	Eligible tagged	Proportion of trap count	Number tagged	Eligible tagged	Proportion of trap count	
	1	2	3	4	5	6	3/6
MSW salmon							
1966	56	38	0.12	164	160	0.12	1.02
1967	21	17	0.23	135	125	0.14	1.72
1968	205	130	0.45	203	189	0.17	2.64
1969	119	96	0.28	128	121	0.37	0.77
1970	102	72	0.58	101	99	0.83	0.70
1971	314	186	0.50	11	11	0.46	1.08
1972	349	346	0.37	106	106	0.49	0.76
1973	307	305	0.64	313	311	0.48	1.34
1974	274	271	0.31	287	287	0.31	1.01
1975	140	137	0.22	125	123	0.21	1.03
1985	198	196	0.68	24	24	1.00	0.68
1986	244	238	0.69	111	111	0.90	0.77
1987	203	198	0.89	66	66	0.97	0.91
1SW salmon							
1966	253	221	0.05	416	372	0.07	0.71
1967	144	123	0.08	464	428	0.07	1.18
1968	255	204	0.08	79	75	0.10	0.81
1969	254	197	0.06	69	64	0.06	1.08
1970	195	161	0.09	65	64	0.10	0.91
1971	179	150	0.08	29	29	0.26	0.32
1972	430	429	0.18	71	71	0.43	0.42
1973	154	152	0.10	452	452	0.47	0.22
1974	780	778	0.26	361	359	0.33	0.80
1975	614	612	0.21	126	126	0.21	0.98
1985	589	580	0.64	11	11	1.00	0.64
1986	1033	983	0.74	388	386	0.88	0.84
1987	935	920	0.80	105	105	0.83	0.96

Table 5. Summary of tag recaptures from various fisheries of tags applied to adult Atlantic salmon at Millbank, 1966-1987. Recaptures are for year of tagging only.

Year	Number tagged	Drift nets	Trap nets	Native	Hatchery	Poached	Misc.*	Angling	Total	Proportion recaptured
1SW salmon										
1966	669	—	25	—	39	8	4	72	148	0.22
1967	608	—	29	—	19	8	1	59	116	0.19
1968	334	1	48	1	4	1	—	46	101	0.30
1969	323	—	54	—	6	1	1	67	129	0.40
1970	260	—	34	—	—	—	1	42	77	0.30
1971	208	—	27	2	—	—	—	36	65	0.31
1972	501	—	—	—	—	1	—	88	89	0.18
1973	606	—	—	1	—	1	—	29	31	0.05
1974	1141	—	—	2	—	2	—	158	162	0.14
1975	740	—	—	1	—	—	1	88	90	0.12
1985	600	—	—	7	—	—	2	68	77	0.13
1986	1421	—	—	51	—	1	—	141	193	0.14
1987	1040	—	—	14	—	—	1	89	104	0.10
TOTAL	8451	1	217	79	68	23	11	983	1382	0.16
MSW salmon										
1966	220	2	12	—	4	4	—	9	31	0.14
1967	156	1	7	—	4	2	—	13	27	0.17
1968	408	14	61	1	10	2	1	50	139	0.34
1969	247	2	23	—	5	—	—	35	65	0.26
1970	203	5	26	—	1	—	—	22	54	0.27
1971	325	59	60	8	—	1	—	32	160	0.49
1972	455	—	—	2	—	—	1	64	67	0.15
1973	620	—	—	2	—	1	1	61	65	0.10
1974	561	—	—	3	—	—	—	42	45	0.08
1975	265	—	1	4	—	—	—	13	18	0.07
1985	222	—	—	2	—	—	—	15	17	0.08
1986	355	—	—	6	—	—	—	15	21	0.06
1987	269	—	—	5	—	—	—	2	7	0.02
TOTAL	4306	83	190	33	24	10	3	373	716	0.17

* unspecified gear; mortalities in river.

Table 6. Summary of recaptures from various research counting facilities of tags applied to adult Atlantic salmon at Millbank, 1966-1987. Recaptures are for year of tagging only.

Year	Number tagged	Recapture traps					DNRE barriers			Proportion recaptured
		Millbank	NW	SW	Curventon	Bartholomew	Dungarvon	SW	Total	
1SW salmon										
1966	669	5	—	—	6	—	—	—	11	0.02
1967	608	—	—	—	—	—	—	—	—	0.00
1968	334	—	—	—	3	—	—	—	3	0.01
1969	323	1	—	—	3	—	—	—	4	0.01
1970	260	2	—	—	—	—	—	—	2	0.01
1971	208	—	—	—	2	—	—	—	2	0.01
1972	501	1	—	—	8	—	—	—	9	0.02
1973	606	1	24	54	8	—	—	—	87	0.14
1974	1141	20	—	—	—	—	—	—	20	0.02
1975	740	9	—	—	—	—	—	—	9	0.01
1985	600	—	5	10	—	1	4	—	20	0.03
1986	1421	7	9	17	—	1	3	1	38	0.03
1987	1040	7	7	6	—	12	2	—	34	0.03
TOTAL	8451	53	45	87	30	14	9	1	239	0.03
MSW salmon										
1966	220	—	—	—	—	—	—	—	—	0.00
1967	156	—	—	—	—	—	—	—	—	0.00
1968	408	—	—	—	2	—	—	—	2	0.01
1969	247	—	—	—	—	—	—	—	—	0.00
1970	203	—	—	—	2	—	—	—	2	0.01
1971	325	1	—	—	1	—	—	—	2	0.01
1972	455	1	—	—	4	—	—	—	5	0.01
1973	620	2	20	35	8	—	—	—	65	0.10
1974	561	2	—	—	—	—	—	—	2	0.00
1975	265	—	—	—	—	—	—	—	—	0.00
1985	222	1	—	4	—	—	—	—	5	0.02
1986	355	2	5	3	—	—	—	—	10	0.03
1987	269	—	3	4	—	2	—	—	9	0.03
TOTAL	4306	9	28	46	17	2	—	—	102	0.02

Table 7. Test for heterogeneity in the proportion of marked salmon in the recaptured sample at tidal research traps located in the Southwest and Northwest tributaries, 1973 and 1985 to 1987. (X^2 is the chi-square value, with the associated probability level p).

	Southwest trap		Northwest trap			
Year	Catch	Marked	Catch	Marked	X^2	p
1973	6651	89	3532	44	0.15	0.70
1985	1320	14	894	5	1.64	0.20
1986	2084	20	1082	14	0.71	0.40
1987	1078	10	927	10	0.11	0.74

Table 8. Test for heterogeneity in the proportion of marked salmon in the recaptured sample from the angling fishery in the Northwest and Southwest tributaries, 1969-1987.

	Southwest		Northwest			
Year	Catch	Marked	Catch	Marked	X^2	p
1969	23033	84	4901	18	<0.01	0.98
1970	17729	52	5066	10	1.43	0.23
1971	12210	49	3229	19	1.88	0.17
1972	23095	119	4783	33	2.07	0.15
1973	15584	71	4161	19	<0.01	0.99
1974	19941	153	5258	47	0.81	0.37
1975	17210	75	4567	26	1.31	0.25
1985[a]	8986	22	9385	46	7.62	<0.01
1986[a]	16527	91	9491	46	0.50	0.48
1987[a]	13610	60	7068	27	0.39	0.53

[a] Samples from 1985 to 1987 include 1SW salmon only.

Table 9. Comparison of the tagged to untagged salmon ratio (*s/n*) from recapture traps located in tidal waters and from anglers. The difference in ratios (Rate) is attributed to non-reporting and non-detection of tags by anglers, and to tag mortalities and tag losses in tributaries above the head of tide.

	Recapture traps			Anglers			
Year	*n*	*s*	*s/n*	*n*	*s*	*s/n*	Rate
1	2	3	4	5	6	7	7/4
1973	10316	78	0.0076	19834	83	0.0042	0.55
1985	1543	15	0.0097	18439	68	0.0037	0.38
1986	2351	23	0.0098	26163	138	0.0053	0.54
1987	1539	13	0.0084	20765	91	0.0044	0.52
Mean			0.0089			0.0044	0.50

Table 10. Summary of data used to estimate angling exploitation and spawning escapement in the Miramichi River. t = total fish marked; t_e = marked early; t_l = marked late; *Cor* = correction factor (see text); n = angling catch; s_e = early recaptures; s_l = late recaptures.

Year	t	t_e	t_l	*Cor*	n	s_e	s_l
1SW salmon							
1966	593	221	372	0.71	40636	34	38
1967	551	123	428	1.18	34739	28	31
1968	279	204	75	0.81	14235	37	9
1969	261	197	64	1.08	24284	59	8
1970	225	161	64	0.91	19610	34	8
1971	179	150	29	0.32	13727	36	0
1972	500	429	71	0.42	19101	86	2
1973	604	152	452	0.22	13857	24	5
1974	1137	778	359	0.80	18232	151	7
1975	738	612	126	0.98	15598	86	2
1985	591	580	11	0.64	18439	68	0
1986	1369	983	386	0.84	26163	121	20
1987	1025	920	105	0.96	20765	89	2
MSW salmon							
1966	198	38	160	1.02	6504	2	7
1967	142	17	125	1.72	5236	4	9
1968	319	130	189	2.64	3257	28	22
1969	217	96	121	0.77	3804	15	20
1970	171	72	99	0.70	3268	16	6
1971	197	186	11	1.08	1792	31	1
1972	452	346	106	0.76	8933	62	2
1973	616	305	311	1.34	5977	52	9
1974	558	271	287	1.01	7184	36	6
1975	260	137	123	1.03	6288	11	2

Table 11. Angling exploitation rate of early-run (U_e), late-run (U_l) and total Atlantic salmon in the Miramichi River, 1966 to 1975 and 1985 to 1987. (95% CL in parenthesis).

Year	U_e	U_l	U
	Early-run	Late-run	Total
1SW salmon			
1966	0.28 (0.22, 0.36)	0.19 (0.14, 0.25)	0.23 (0.19, 0.28)
1967	0.41 (0.31, 0.54)	0.13 (0.10, 0.17)	0.19 (0.16, 0.22)
1968	0.33 (0.26, 0.42)	0.22 (0.13, 0.37)	0.30 (0.24, 0.38)
1969	0.54 (0.45, 0.66)	0.23 (0.14, 0.37)	0.46 (0.39, 0.55)
1970	0.38 (0.30, 0.49)	0.23 (0.13, 0.39)	0.34 (0.27, 0.43)
1971	0.44 (0.34, 0.56)	0.00	0.41 (0.32, 0.52)
1972	0.36 (0.31, 0.43)	0.05 (0.01, 0.22)	0.34 (0.29, 0.40)
1973	0.29 (0.21, 0.39)	0.02 (0.01, 0.07)	0.18 (0.14, 0.24)
1974	0.35 (0.31, 0.40)	0.04 (0.02, 0.06)	0.27 (0.24, 0.30)
1975	0.26 (0.22, 0.30)	0.03 (0.01, 0.08)	0.22 (0.19, 0.25)
1985	0.31 (0.27, 0.36)	0.00	0.30 (0.26, 0.35)
1986	0.23 (0.20, 0.26)	0.10 (0.07, 0.14)	0.20 (0.17, 0.22)
1987	0.18 (0.16, 0.21)	0.04 (0.01, 0.10)	0.17 (0.15, 0.20)
Mean	0.34	0.10	0.28
MSW salmon			
1966	0.10 (0.04, 0.26)	0.08 (0.05, 0.14)	0.08 (0.05, 0.13)
1967	0.43 (0.21, 0.87)	0.13 (0.09, 0.19)	0.15 (0.11, 0.21)
1968	0.39 (0.30, 0.52)	0.21 (0.17, 0.26)	0.25 (0.21, 0.29)
1969	0.28 (0.20, 0.41)	0.30 (0.21, 0.43)	0.29 (0.22, 0.38)
1970	0.40 (0.28, 0.58)	0.11 (0.05, 0.22)	0.26 (0.19, 0.36)
1971	0.30 (0.23, 0.39)	0.17 (0.04, 0.61)	0.29 (0.23, 0.38)
1972	0.33 (0.27, 0.39)	0.03 (0.01, 0.11)	0.27 (0.23, 0.32)
1973	0.31 (0.25, 0.38)	0.05 (0.03, 0.08)	0.16 (0.13, 0.19)
1974	0.24 (0.19, 0.31)	0.04 (0.02, 0.07)	0.14 (0.11, 0.17)
1975	0.15 (0.09, 0.23)	0.03 (0.01, 0.08)	0.09 (0.06, 0.13)
Mean	0.29	0.12	0.20

Table 12. Comparison of angling exploitation rate of early-run (U_e) and late-run (U_l) salmon in the Miramichi River when the duration of the angling fishery was decreased from 139 to 124 fishing days. (The decrease was at the end of the angling season and thus affected late-run moreso than early-run salmon).

Period	Season (duration)	1SW			MSW		
		U_e	U_l	U	U_e	U_l	U
66-70	139	0.39	0.20	0.30	0.32	0.17	0.21
72-75	124	0.32	0.04	0.25	0.26	0.04	0.17

Table 13. Estimated total river returns and spawning escapement as estimated from angling mark-recapture data and Millbank trap data. Millbank data are from Randall and Schofield (1988).

Year	Returns (95% CL)	Spawners (angling)	Spawners (Millbank)
1SW salmon			
1966	177,801 (147,639 - 214,131)		
1967	185,810 (155,100 - 222,606)		
1968	46,800 (37,633 - 58,204)		
1969	52,548 (44,044 - 62,695)		
1970	57,282 (45,704 - 71,797)		
1971	33,404 (26,231 - 42,540)	15,677	17,946
1972	55,506 (47,497 - 64,868)	32,405	23,135
1973	76,347 (57,173 - 101,963)	58,490	26,688
1974	68,208 (60,732 - 76,605)	45,976	51,186
1975	71,733 (61,443 - 83,748)	52,135	44,469
1985	60,489 (52,252 - 70,027)	38,050	23,432
1986	134,025 (118,558 - 151,512)	103,862	78,567
1987	121,232 (104,543 - 140,586)	96,467	75,266
MSW salmon			
1966	78,745 (48,892 - 126,910)		
1967	34,297 (24,707 - 47,619)		
1968	13,089 (11,192 - 15,307)		
1969	13,019 (10,009 - 16,936)		
1970	12,573 (9,110 - 17,354)		
1971	6,080 (4,706 - 7,854)	3,288	6,487
1972	32,994 (27,499 - 39,587)	23,061	16,834
1973	37,037 (30,893 - 44,404)	30,060	19,349
1974	52,689 (42,128 - 65,902)	44,505	33,467
1975	69,827 (46,818 - 104,181)	62,539	20,467

Table 14. Angling exploitation rates of Atlantic salmon in rivers of Canada and the United States. Where possible, the range in rates among years is reported in parentheses.

River	Duration of study (years)	Exploitation rate						Authority	
		1SW		MSW		Both			
Miramichi	13	0.28	(0.17–0.46)	0.20	(0.08–0.29)			This study	
NW Miramichi	10	0.39		0.52				Elson	1974
Saint John	5	0.29	(0.21–0.40)					Anon.	1988
Big Salmon	10					0.24	(0.07–0.55)	Jessop	1986
LaHave	6	0.24		0.23		0.23		Gray	1986
Exploits	16	0.28	(0.15–0.46)					Chadwick	1982
Western Arm	4	0.25	(0.22–0.30)					Chadwick	1982
Penobscot	9			0.25	(0.13–0.35)			Anon.	1989

Table 15a. Relative standard errors of estimates of spawning escapement for a hypothetical salmon population, where N=50,000; exploitation rate is 0.30 (n=15,000); tagging ratios of 1% (t=500, s=150), 2% (t=1000, s=300) and 4% (t=2000, s=600), tag reporting rates of 1.0 and 0.5, and standard errors for reporting rate (a) and angling catch (k) as indicated.

		N=50,000		n=15,000		M=35,000	
		t=500, s=150		t=1000, s=300		t=2000, s=600	
k	a	1.0	0.5	1.0	0.5	1.0	0.5
0	0	11.6	16.4	8.2	11.6	5.7	8.2
	.01	11.7	16.5	8.3	11.7	5.9	8.3
	.05	13.6	17.9	10.8	13.6	9.2	10.8
	.10	18.4	21.8	16.4	18.4	15.4	16.4
.01	0	11.6	16.5	8.2	11.7	5.8	8.3
	.01	11.7	16.6	8.4	11.8	6.0	8.4
	.05	13.7	18.0	10.9	13.7	9.3	11.0
	.10	18.5	21.9	16.6	18.5	15.6	16.7
.05	0	12.6	17.9	9.5	13.6	7.5	10.8
	.01	12.7	18.0	9.7	13.7	7.8	10.9
	.05	14.8	19.5	12.7	15.9	12.0	14.3
	.10	20.0	23.7	19.2	21.5	20.3	21.7
.10	0	15.3	21.6	12.8	18.2	11.3	16.2
	.01	15.4	21.7	13.0	18.4	11.7	16.4
	.05	17.9	23.6	17.0	21.4	18.1	21.5
	.10	24.2	28.6	25.8	28.9	30.5	32.6
.20	0	22.9	32.6	21.4	30.4	20.4	29.1
	.01	23.1	32.7	21.7	30.6	21.2	29.6
	.05	27.0	35.5	28.4	35.7	32.6	38.7
	.10	36.4	43.1	43.1	48.2	54.9	58.7

Table 15b. Relative standard errors of estimates of spawning escapement for a hypothetical salmon population, where N=50,000; exploitation rate is 0.20 (n=10,000); tagging ratios of 1% (t=500, s=100), 2% (t=1000, s=200) and 4% (t=2000, s=400), tag reporting rates of 1.0 and 0.5, and standard errors for reporting rate (a) and angling catch (k) as indicated.

		N=50,000		n=10,000		N=40,000	
		t=500, s=100		t=1000, s=200		t=2000, s=400	
k	a	1.0	0.5	1.0	0.5	1.0	0.5
0	0	12.4	17.6	8.8	12.4	6.1	8.8
	.01	12.5	17.7	8.8	12.5	6.2	8.8
	.05	13.9	18.7	10.8	14.0	8.8	10.8
	.10	17.6	21.6	15.3	17.6	13.9	15.3
.01	0	12.5	17.7	8.8	12.5	6.2	8.9
	.01	12.5	17.7	8.9	12.6	6.3	9.0
	.05	14.0	18.8	10.8	14.0	8.9	10.9
	.10	17.7	21.7	15.4	17.8	14.1	15.4
.05	0	13.4	19.0	10.0	14.3	7.8	11.2
	.01	13.5	19.0	10.2	14.4	8.0	11.3
	.05	15.0	20.1	12.4	16.0	11.2	13.8
	.10	19.0	23.3	17.5	20.2	17.8	19.5
.10	0	15.9	22.6	13.2	18.8	11.6	16.5
	.01	16.0	22.6	13.3	18.9	11.8	16.7
	.05	17.8	23.9	16.2	21.0	16.5	20.3
	.10	22.6	27.6	23.0	26.6	26.2	28.8
.20	0	23.4	33.2	21.8	30.7	20.2	29.3
	.01	23.5	33.3	21.8	30.9	20.9	29.6
	.05	26.2	35.2	26.6	34.4	29.3	36.0
	.10	33.2	40.7	37.7	43.6	46.6	51.1

Table 15c. Relative standard errors of estimates of spawning escapement for a hypothetical salmon population, where N=100,000; exploitation rate is 0.20 (n=20,000); tagging ratios of 1% (t=1000, s=200), 2% (t=2000, s=400) and 4% (t=4000, s=800), tag reporting rates of 1.0 and 0.5, and standard errors for reporting rate (a) and angling catch (k) as indicated.

		N=100,000		n=20,000		M=80,000	
		t=1000, s=200		t=2000, s=400		t=4000, s=800	
k	a	1.0	0.5	1.0	0.5	1.0	0.5
0	0	8.8	12.5	6.2	8.8	4.3	6.2
	.01	8.9	12.5	6.3	8.9	4.5	6.3
	.05	10.8	14.0	8.8	10.8	7.6	8.8
	.10	15.3	17.7	14.0	15.3	13.2	14.0
.01	0	8.8	12.6	6.3	8.9	4.4	6.3
	.01	8.9	12.6	6.4	9.0	4.6	6.5
	.05	10.9	14.0	8.9	10.9	7.8	9.0
	.10	15.4	17.8	14.1	15.5	13.6	14.3
.05	0	10.1	14.3	7.9	11.3	6.5	9.3
	.01	10.2	14.4	8.1	11.4	6.8	9.5
	.05	12.4	16.0	11.3	13.8	11.5	13.3
	.10	17.6	20.3	17.9	19.6	20.0	21.1
.10	0	13.3	18.8	11.7	16.6	10.7	15.3
	.01	13.4	18.9	11.9	16.8	11.2	15.6
	.05	16.3	21.0	16.6	20.4	18.8	21.8
	.10	23.1	26.6	26.3	28.8	32.7	34.5
.20	0	21.7	30.8	20.7	29.5	20.1	28.7
	.01	22.0	31.0	21.2	29.8	20.9	29.2
	.05	26.7	34.5	29.5	36.2	35.2	40.7
	.10	37.8	43.6	46.7	51.2	61.3	64.6

Table 15d. Relative standard errors of estimates of spawning escapement for a hypothetical salmon population, where N=100,000; exploitation rate is 0.30 (n=30,000); tagging ratios of 1% (t=1000,s=300), 2% (t=2000,s=600) and 4% (t=4000,s=1200), tag reporting rates of 1.0 and 0.5, and standard errors for reporting rate (a) and angling catch (k) as indicated.

		N=100,000		n=30,000		M=70,000	
		t=1000,s=300		t=2000,s=600		t=4000,s=1200	
k	a	1.0	0.5	1.0	0.5	1.0	0.5
0	0	8.2	11.6	5.8	8.2	4.0	5.8
	.01	8.3	11.7	6.0	8.3	4.3	6.0
	.05	10.9	13.6	9.2	10.9	8.2	9.2
	.10	16.5	18.4	15.4	16.5	14.8	15.4
.01	0	8.3	11.7	5.9	8.3	4.2	5.9
	.01	8.4	11.8	6.0	8.4	4.4	6.1
	.05	11.0	13.8	9.3	11.0	8.4	9.4
	.10	16.6	18.6	15.6	16.7	15.3	15.8
.05	0	9.6	13.6	7.6	10.8	6.4	9.1
	.01	9.7	13.7	7.8	11.0	6.7	9.3
	.05	12.7	16.0	12.1	14.3	12.9	14.4
	.10	19.3	21.5	20.3	21.7	23.3	24.2
.10	0	12.9	18.3	11.4	16.3	10.6	15.1
	.01	13.1	18.4	11.8	16.5	11.2	15.6
	.05	17.1	21.4	18.2	21.6	21.5	24.1
	.10	25.9	28.9	30.6	32.7	38.9	40.4
.20	0	21.5	30.5	20.6	29.3	20.0	28.6
	.01	21.8	30.7	21.2	29.7	21.2	29.4
	.05	28.5	35.8	32.8	38.8	40.6	45.5
	.10	43.1	48.2	55.0	58.8	73.5	76.3

Table 15e. Relative standard errors of estimates of spawning escapement for a hypothetical salmon population, where N=200,000; exploitation rate is 0.20 (n=40,000); tagging ratios of 1% (t=2000,s=400), 2% (t=4000,s=800) and 4% (t=8000,s=1600), tag reporting rates of 1.0 and 0.5, and standard errors for reporting rate (a) and angling catch (k) as indicated.

		N=200,000		n=40,000		M=160,000	
		t=2000,s=400		t=4000,s=800		t=8000,s=1600	
k	a	1.0	0.5	1.0	0.5	1.0	0.5
0	0	6.2	8.8	4.4	6.2	3.1	4.4
	.01	6.3	8.9	4.6	6.3	3.3	4.6
	.05	8.8	10.8	7.6	8.8	7.0	7.6
	.10	14.0	15.3	13.2	14.0	12.9	13.2
.01	0	6.3	8.9	4.5	6.4	3.2	4.6
	.01	6.4	9.0	4.7	6.5	3.5	4.8
	.05	8.9	10.9	7.8	9.0	7.3	8.0
	.10	14.1	15.5	13.6	14.3	13.5	13.9
.05	0	8.0	11.3	6.6	9.4	5.8	8.3
	.01	8.1	11.4	6.9	9.6	6.2	8.6
	.05	11.3	13.8	11.5	13.3	13.1	14.4
	.10	17.9	19.6	20.0	21.1	24.3	25.0
.10	0	11.7	16.6	10.8	15.4	10.3	14.7
	.01	12.0	16.8	11.2	15.7	11.1	15.2
	.05	16.6	20.4	18.9	21.8	23.3	25.6
	.10	26.3	28.8	32.8	34.5	43.1	44.4
.20	0	20.8	29.5	20.3	28.8	19.8	28.3
	.01	21.2	29.8	21.1	29.4	21.4	29.5
	.05	29.5	36.2	35.4	40.8	45.1	49.4
	.10	46.8	51.2	61.4	64.7	83.4	85.8

Table 15f. Relative standard errors of estimates of spawning escapement for a hypothetical salmon population, where N=200,000; exploitation rate is 0.30 (n=60,000); tagging ratios of 1% (t=2000, s=600), 2% (t=4000, s=1200) and 4% (t=8000, s=2400), tag reporting rates of 1.0 and 0.5, and standard errors for reporting rate (a) and angling catch (k) as indicated.

		N=200,000		n=60,000		M=140,000	
		t=2000, s=600		t=4000, s=1200		t=8000, s=2400	
k	a	1.0	0.5	1.0	0.5	1.0	0.5
0	0	5.8	8.2	4.1	5.8	2.9	4.1
	.01	6.0	8.4	4.3	6.0	3.2	4.3
	.05	9.2	10.9	8.2	9.2	7.7	8.2
	.10	15.4	16.5	14.9	15.4	14.6	14.8
.01	0	5.9	8.4	4.2	6.0	3.0	4.3
	.01	6.1	8.5	4.4	6.2	3.4	4.6
	.05	9.3	11.0	8.5	9.5	8.1	8.7
	.10	15.6	16.7	15.3	15.9	15.4	15.7
.05	0	7.6	10.8	6.4	9.1	5.7	8.1
	.01	7.9	11.0	6.8	9.4	6.3	8.6
	.05	12.2	14.4	12.9	14.5	15.3	16.3
	.10	20.3	21.7	23.3	24.2	28.2	29.5
.10	0	11.5	16.3	10.7	15.2	10.2	14.6
	.01	11.8	16.6	11.3	15.7	11.4	15.4
	.05	18.2	21.6	21.6	24.1	27.4	29.4
	.10	30.6	32.7	39.0	40.4	52.0	53.1
.20	0	20.7	29.4	20.2	28.7	19.8	28.3
	.01	21.3	29.8	21.4	29.6	22.1	30.0
	.05	32.8	38.9	40.7	45.6	53.3	57.0
	.10	55.0	58.8	73.5	76.3	101.0	103.0

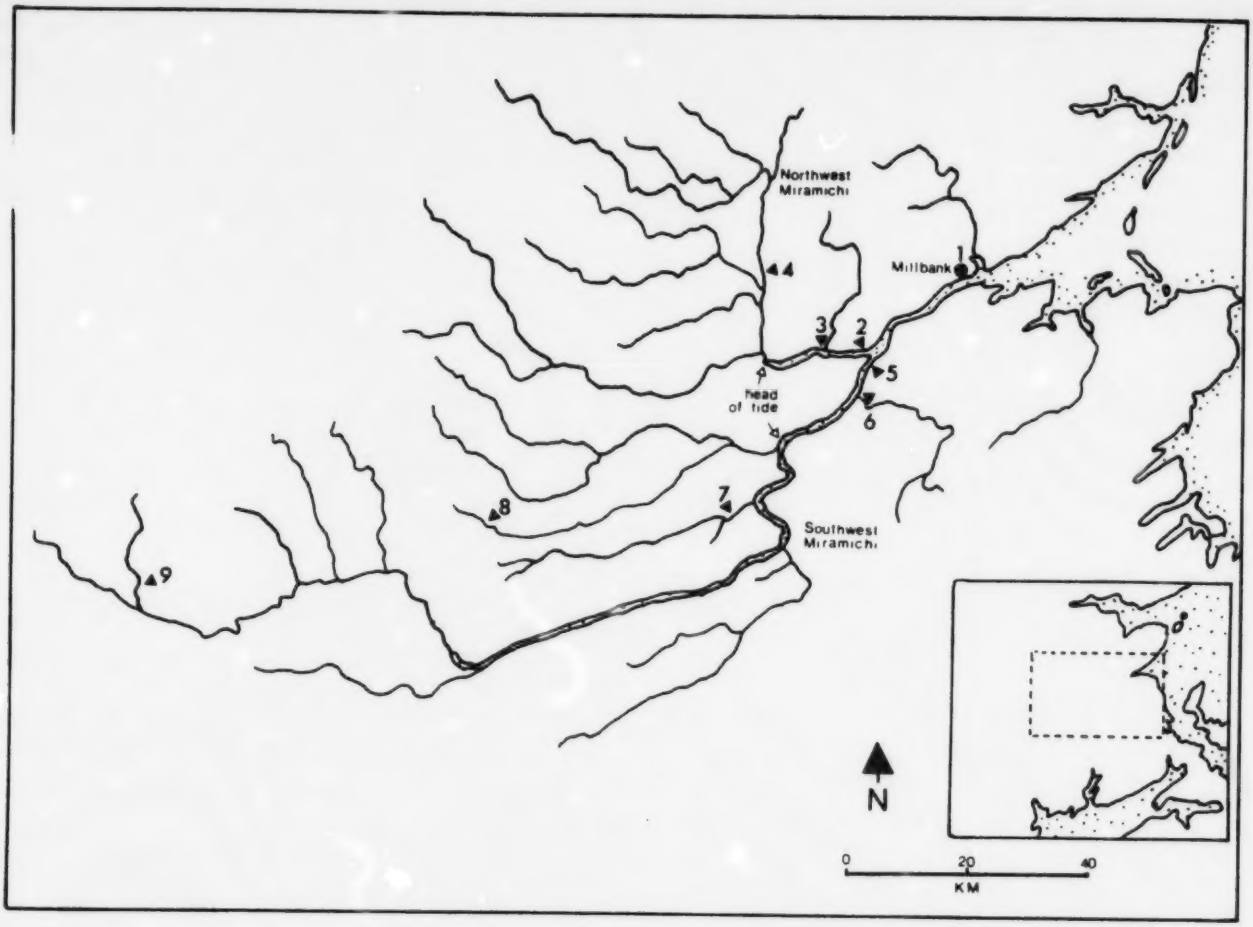

Figure 1. Map of the Miramichi River showing the location of the tagging site and the recapture sites. Atlantic salmon were tagged in the Miramichi estuary at Millbank (1). Recapture locations were: 2 - Northwest Miramichi at the Enclosure park, 1985 to 1987; 3 - Northwest Miramichi at Stathadam, 1973; 4 - Curventon, 1966 to 1973; 5 - Southwest Miramichi at the Enclosure park, 1985 to 1987; 6 - Southwest Miramichi at Millerton, 1973; 7 - Bartholomew River, 1985 to 1987; 8 - Dungarvon River, 1985 to 1987; and 9 - Southwest Miramichi barrier in headwaters, 1985 to 1987. The inset shows the location of the Miramichi watershed in eastern Canada.

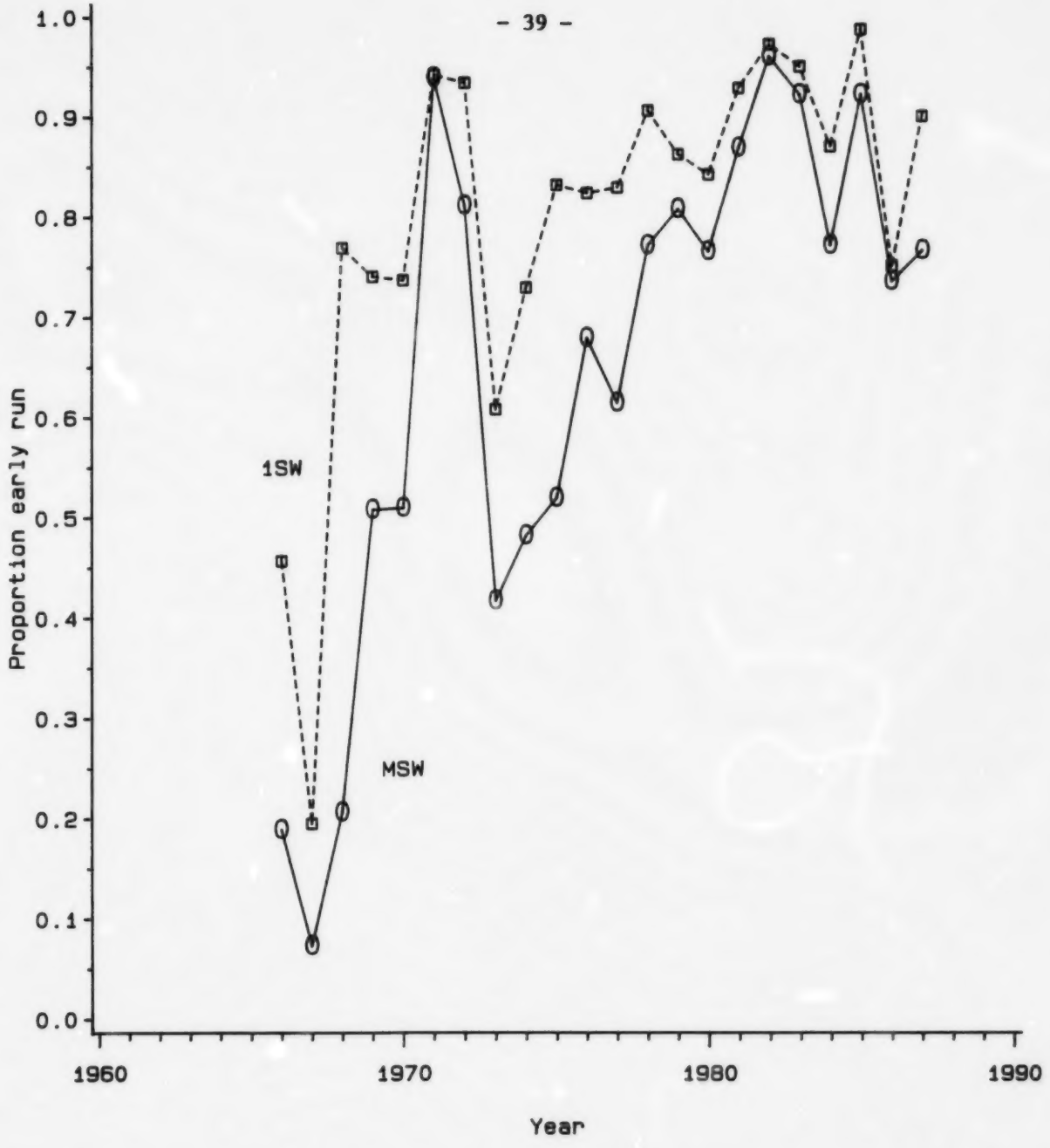

Fig. 2 Proportion of 1SW and MSW salmon which returned to Miramichi River early (before August 31) and late (September to November) each year, 1967 to 1987.

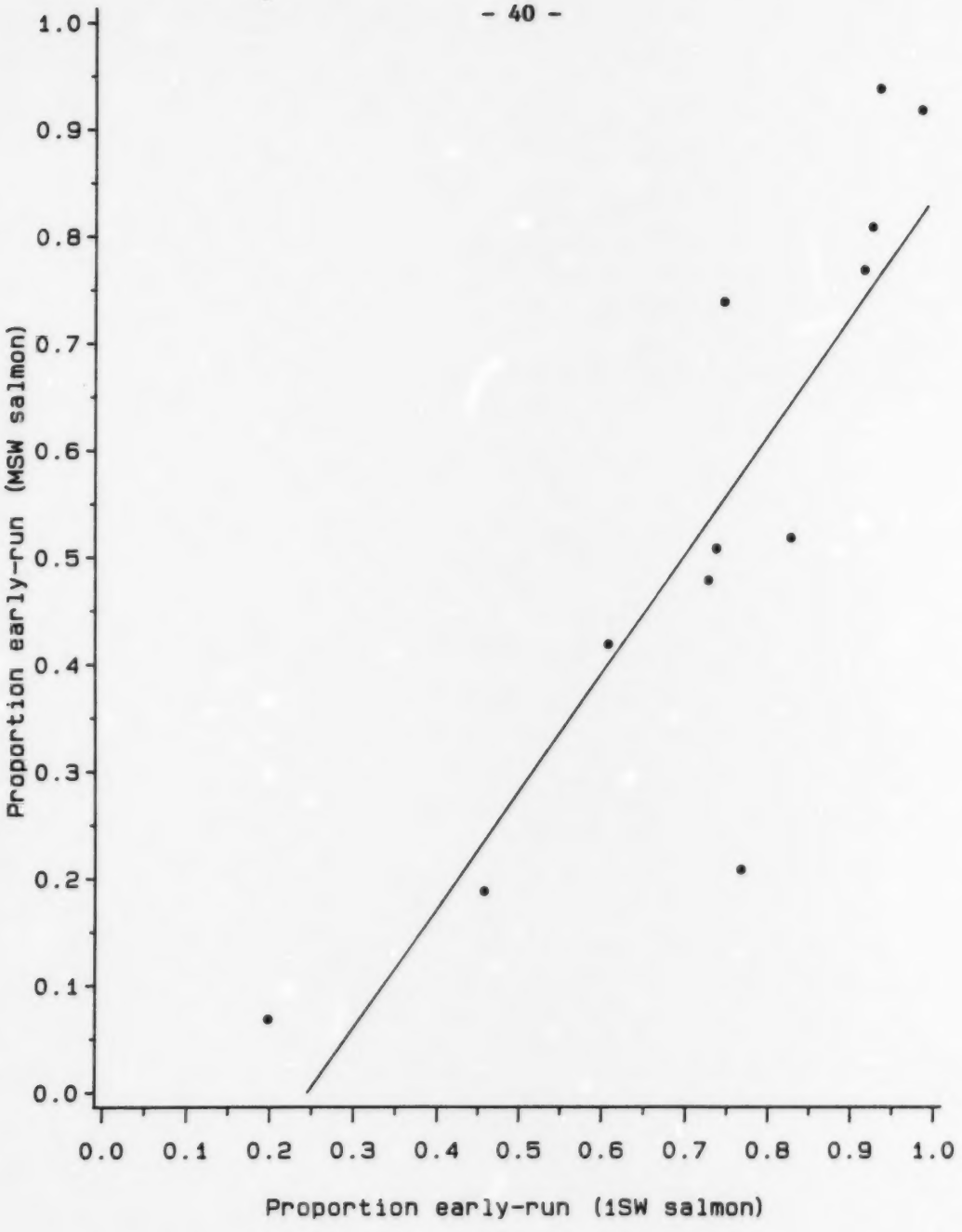

Fig. 3 Relationships between the proportion of early-run 1SW salmon and the proportion of early-run MSW salmon in the Miramichi River, 1966-1975 and 1985-1987.

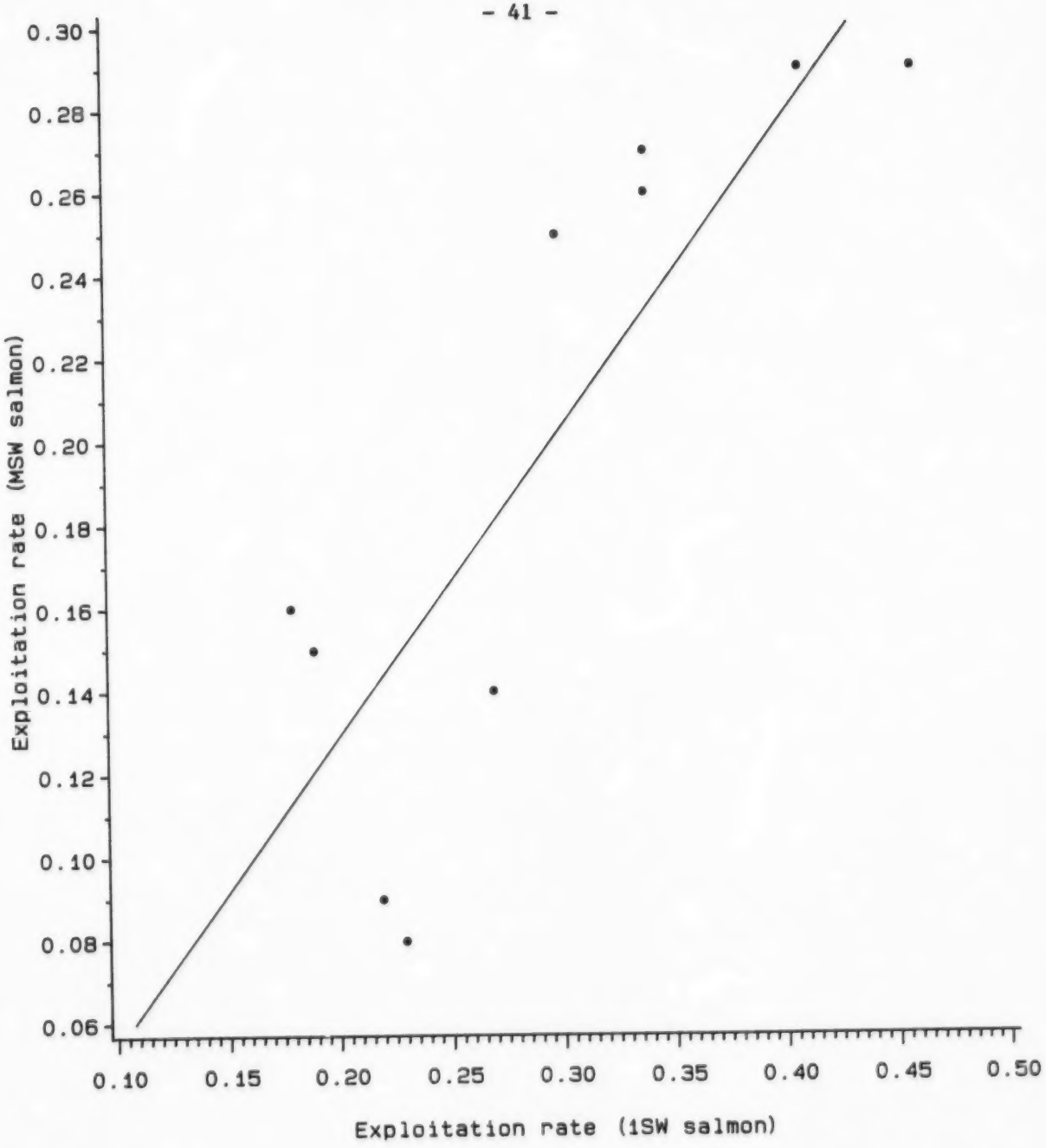

Fig. 4 Correlation between the angling exploitation rate of MSW salmon and 1SW salmon in Miramichi River, 1966-1975. ($R^2 = 0.71$, $P < 0.05$)

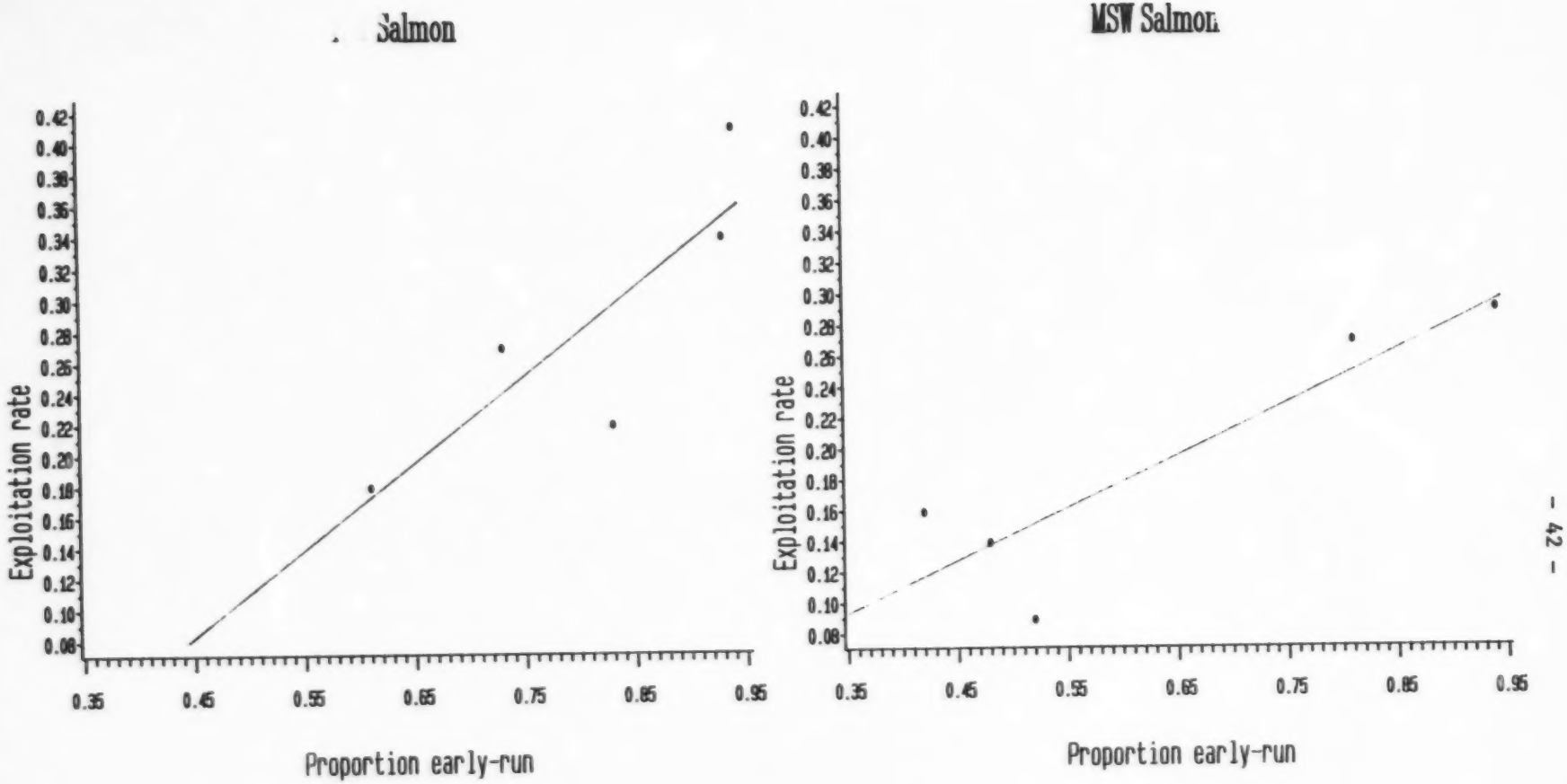

Fig. 5 Correlation between the proportion of salmon that enter the river early (before August 31) and angling exploitation rate. (For 1SW salmon, $R^2=0.72$, $P<0.10$, for MSW salmon, $R^2=0.80$, $P<0.05$)

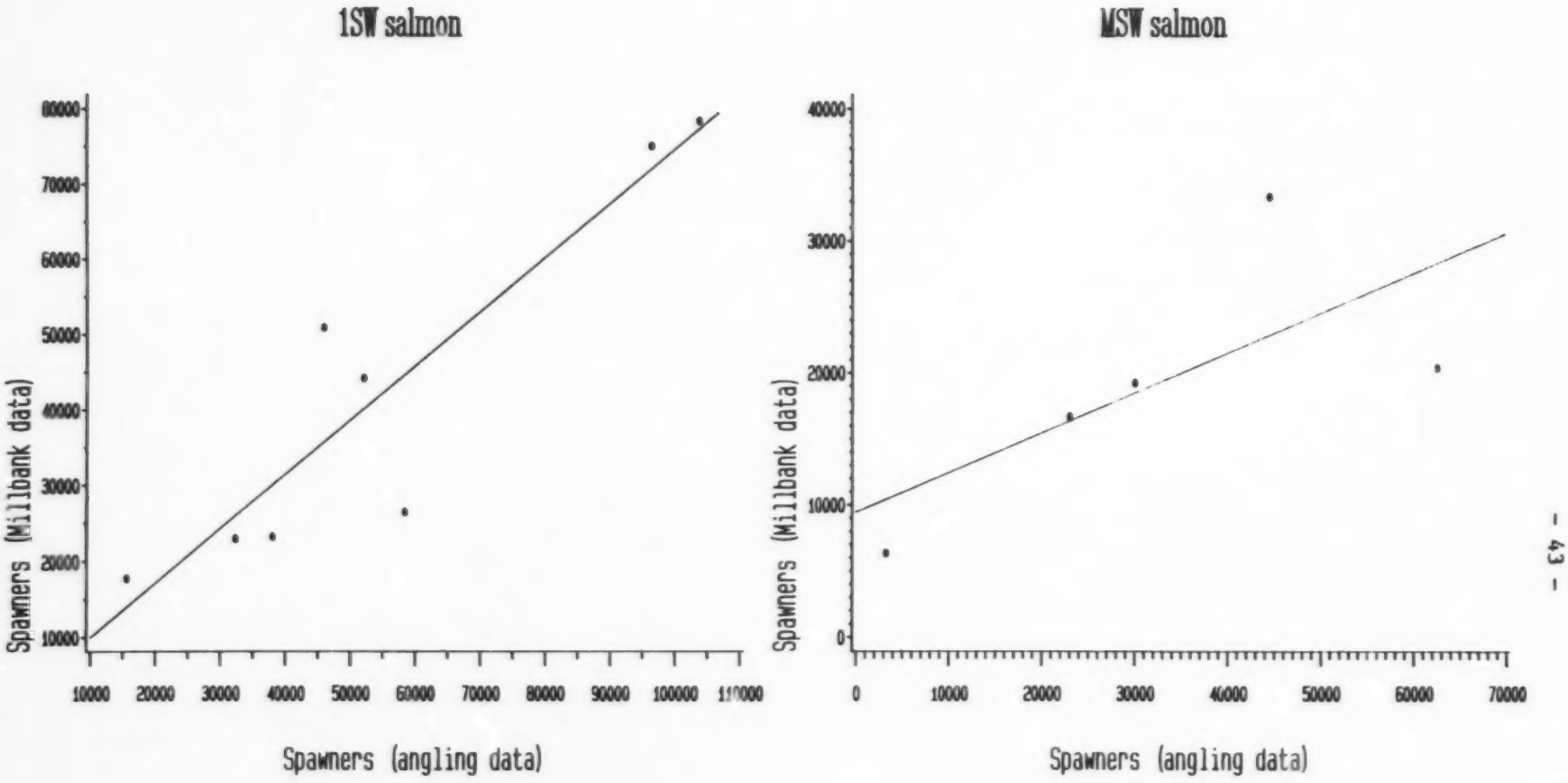

Fig. 6 Correlation between numbers of salmon spawners as estimated from angling mark-recapture data and Millbank trap data. (For 1SW salmon, R^2=0.84, $P < 0.01$, for MSW salmon, R^2= 0.49, NS)

Appendix I.

Assume a total spawning run (N) of 100,000 salmon in the Miramichi River, of which 50% enter the river early (before August 31). Exploitation rate (U) by anglers is 0.3 for early-run fish and 0.1 for late-run fish. Thus the total exploitation rate would be 0.2:

	Early	Late	Total
N	50,000	50,000	100,000
U	0.3	0.1	0.2
n	15,000	5,000	20,000

Exploitation rate in the above population is estimated from a mark-recapture experiment, where salmon are tagged at Millbank. Assume Millbank trap intercepts 0.02 of the salmon run, and 0.3 and 0.7 of the run are marked during the early and late periods, respectively (i.e., marking is not random with respect to run-timing). Tagging data would therefore indicate an exploitation rate which is negatively biased:

	Early	Late	Total
Trap count	1,000	1,000	2,000
t	300	700	1,000
s	90	70	160

Using unadjusted data, exploitation rate would be calculated as:

$$U=(s_0+s_1)/(t_0+t_1)$$
$$=(90+70)/(300+700)$$
$$=0.16$$

Biased marking can be adjusted by using a correction factor (Cor)

$$Cor=a1/a2$$

where *a1* and *a2* are the proportions of early-run and late-run salmon tagged, respectively. For the above example, *Cor* = 0.3/0.7 = 0.43.

Therefore, using adjusted data, exploitation rate is calculated as:

$$U = [s_e + s_l(Cor)] / [t_e + t_l(Cor)]$$
$$= [90 + 70(0.43)] / [300 + 700(0.43)]$$
$$= 0.20$$

Appendix II. Angling exploitation rate for early and late-run Atlantic salmon in the Miramichi River as estimated using four different assumptions for tag reporting rate (see text pg. 7).

Year	Early-run				Late-run			
	1	2	3	4	1	2	3	4
1SW Salmon								
1966	0.15	0.19	0.28	0.35	0.10	0.13	0.19	0.23
1967	0.23	0.28	0.41	0.52	0.07	0.09	0.13	0.16
1968	0.18	0.23	0.33	0.41	0.12	0.15	0.22	0.27
1969	0.30	0.37	0.54	0.68	0.13	0.16	0.23	0.28
1970	0.21	0.26	0.38	0.48	0.13	0.16	0.23	0.28
1971	0.24	0.30	0.44	0.55	0.00	0.00	0.00	0.00
1972	0.20	0.25	0.36	0.46	0.03	0.04	0.05	0.06
1973	0.16	0.20	0.29	0.36	0.01	0.01	0.02	0.03
1974	0.19	0.24	0.35	0.44	0.02	0.02	0.04	0.04
1975	0.14	0.18	0.26	0.32	0.02	0.02	0.03	0.04
1985	0.12	0.15	0.31	0.39	0.00	0.00	0.00	0.00
1986	0.12	0.15	0.23	0.28	0.05	0.06	0.10	0.12
1987	0.10	0.12	0.19	0.23	0.02	0.02	0.04	0.05
MSW Salmon								
1966	0.05	0.07	0.10	0.12	0.04	0.05	0.08	0.10
1967	0.24	0.29	0.43	0.53	0.07	0.09	0.13	0.16
1968	0.22	0.27	0.39	0.49	0.12	0.15	0.21	0.26
1969	0.16	0.20	0.28	0.36	0.17	0.21	0.30	0.38
1970	0.22	0.28	0.40	0.51	0.06	0.08	0.11	0.14
1971	0.17	0.21	0.30	0.38	0.09	0.11	0.17	0.21
1972	0.18	0.22	0.33	0.41	0.02	0.02	0.03	0.04
1973	0.17	0.21	0.31	0.39	0.03	0.04	0.05	0.07
1974	0.13	0.17	0.24	0.30	0.02	0.03	0.04	0.05
1975	0.08	0.10	0.15	0.18	0.02	0.02	0.03	0.04